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A BIBLIOGRAPHY OF RECENT DEVELOPMENTS IN UNSTEADY TRANSONIC FLO--ETC(U)
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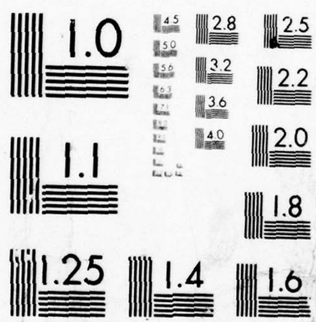

MICROCOPY RESOLUTION TEST CHART
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AFFDL-TR-78-189
Volume I

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LEVEL II

A BIBLIOGRAPHY OF RECENT DEVELOPMENTS IN UNSTEADY TRANSONIC FLOW

Volume I

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THE BOEING COMPANY
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SEATTLE, WASHINGTON 98124

FEBRUARY 1979

TECHNICAL REPORT AFFDL-TR-78-189, Volume I
Report for Period 15 May 1978 to 15 November 1978

Approved for public release; distribution unlimited.

AIR FORCE FLIGHT DYNAMICS LABORATORY
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AIR FORCE/56780/9 May 1979 — 125

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

19 REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

18

1. REPORT NUMBER: AFFDL-TR-78-189-VOL-1

2. GOVT ACCESSION NO.:

3. RECIPIENT'S CATALOG NUMBER:

6

4. TITLE (and Subtitle): A Bibliography of Recent Developments in Unsteady Transonic Flow.

9

5. TYPE OF REPORT & PERIOD COVERED: Interim Report. 15 May [redacted] - 15 Nov. [redacted]1978

6. PERFORMING ORG. REPORT NUMBER:

10

7. AUTHOR(s): C. J. Borland

15

8. CONTRACT OR GRANT NUMBER(s): F33615-78-C-3201

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
The Boeing Company
P.O. Box 3999
Seattle, Washington 98124

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 16 17 PE 62201F, 2401 02
240102, 24010224

11. CONTROLLING OFFICE NAME AND ADDRESS:
Air Force Flight Dynamics Laboratory (FBE)
Wright-Patterson AFB, Ohio 45433

11

12. REPORT DATE: Feb[redacted] [redacted]979

13. NUMBER OF PAGES: 73

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):

12 73p.

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Transonic Flow	Theoretical	Bibliography	Unsteady
Transonic Aerodynamics	Experimental	Aeroelasticity	Airfoil
Analytical	Numerical	Flutter	Wing
Computational	Nonlinear	Oscillating	Finite Difference

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A bibliography of recent developments in unsteady transonic flow is presented. Papers have been divided into survey, experimental, and theoretical classifications, selected publications have been reviewed, and a more comprehensive set of publications has been listed and summarized in tabular form. Primary emphasis has been placed on numerical solution of unsteady transonic flow problems. Relevant steady methods have been included.

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410 258 LB

FOREWORD

This report was prepared by Boeing Military Airplane Development, The Boeing Company, Seattle, Washington, for the Structural Integrity Branch, and the Analysis and Optimization Branch of the Structural Mechanics Division, Air Force Flight Dynamics Laboratory, Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. Boeing conducted the work under Contract F33615-78-C-3201, "Transonic Unsteady Aerodynamics for Aeroelastic Applications" under Project 2401, and Task 02 Dr. James Olsen of the Structural Mechanics Division is the AFFDL Project Engineer.

The bibliography was prepared during the period May 15, 1978 to November 15, 1978.

The Project Manager for Boeing was Dr. H. Yoshihara and the Principal Investigator was C. J. Borland. The assistance of W. C. Chin, F. E. Ehlers, and D. P. Rizzetta in preparing the reviews is acknowledged.

This bibliography will be updated at yearly intervals throughout the four-year duration of the contract.

TABLE OF CONTENTS

A Bibliography of Recent Developments in Unsteady Transonic Flow

SECTION I INTRODUCTION

The years since 1970 have seen an explosion of information in the field of transonic flow, both steady and unsteady. This has been due to two complementary and not entirely independent factors: first, the renewed interest in aircraft operations, both civil and military, in the transonic flow regime, primarily due to the availability of advanced technology airfoil sections; and second, the development of numerical methods, for the transonic nonlinear partial differential equations and the availability of appropriate computers such as the CDC 7600.

For steady transonic flow, finite difference methods are being used extensively for design purposes in the aircraft industry. The use of numerical solutions for unsteady transonic flow however has been much more limited.

In order to lay the groundwork for further development of methods for transonic unsteady aerodynamics for aeroelastic applications, it is desirable to prepare a bibliography in the field. The primary ground rule in preparation of the bibliography has been that it should primarily include available methods for unsteady transonic flow, classifying them by their characteristic features, and those papers for steady transonic flow which have contributed, or may contribute in the future, to the development of unsteady flow solutions. Since finite difference methods have proven most promising, an attempt has been made to include those steady transonic flow papers which are fundamental to the development, extension, and application of finite difference methods. Thus, for example, papers which describe techniques such as hodograph solutions or integral methods for steady flow have not been included in the review. In addition, experimental studies which provide information useful for correlation purposes have been included. In view of the massive amount

of information available, it has been necessary to establish additional ground rules for elimination of papers from the bibliography. These have excluded papers relating to:

a) Internal aerodynamics, such as flow through inlets and channels, or over cascades in turbomachines;

b) Flow about configurations not directly related to aircraft configurations, such as axisymmetric bodies or spheres;

c) Flows involving rotary wing aircraft;

d) Airfoil or wing design, unless the methods involved are fundamental to the development of transonic flow theory;

e) Those documents not generally accessible or in the open literature.

The development of a comprehensive bibliography list followed these lines:

1) The facilities of the Boeing Company's technical library system were used to search several data bases for documents relevant to steady and unsteady transonic flow, and to aeroelastic applications. Table 1 lists the data bases that were accessed, and the keyword descriptors that were used.

2) A preliminary sorting eliminated those papers which appeared to be irrelevant, did not fit within the ground rules stated above, or appeared as duplicate entries in two or more data bases.

3) The remaining list was cross-checked against several large reference lists in survey papers and against personal files to see that important papers had not been missed.

4) A selected set of papers was chosen for more detailed review. An effort was made to include all those papers which would have a direct bearing on the further development of solutions for unsteady transonic flow. These detailed reviews included classification into categories of survey, theoretical, and experimental papers. For the theoretical papers, further classifications as to the basic equation used, coordinate systems employed, number of mesh points in the finite difference solutions, boundary conditions, numerical algorithms, computation times, and examples given were made. For experimental papers, the facility employed, test section and wall conditions, Mach numbers, motion types and frequencies, and measurements performed were described. If classifications have been omitted, they have not been discernible from the published paper.

5) For those papers not chosen for detailed review, a basic classification into categories of survey paper, theoretical, or experimental was performed where feasible. For theoretical papers, the basic equations, applicable geometries, and numerical methods were determined.

6) A summary chart was prepared for all of the references in the comprehensive list describing the above classifications where possible.

The following sections of this document consist of the detailed reviews for selected papers, a summary chart, and a comprehensive list of references, including author, title, source, date, and accession number (where available).

TABLE 1

DATE BASES SEARCHED	KEYWORDS
NTIS	TRANSONIC FLOW
COMPENDEX	TRANSONIC AERODYNAMICS
INSPEC	ANALYTICAL
DDC	COMPUTATIONAL
NASA	THEORETICAL
	EXPERIMENTAL
	NUMERICAL
	NONLINEAR
	AEROELASTICITY
	FLUTTER
	OSCILLATING
	UNSTEADY
	PRESSURE
	AIRFOIL
	CONTROL
	THREE DIMENSIONAL
	FINITE DIFFERENCE
	WING

SECTION II DETAILED REVIEWS OF SELECTED PAPERS

Using the criteria described above, various papers relating to recent developments in steady and unsteady transonic flow have been selected for more detailed review. Papers and reports have been divided into three basic categories: survey, theoretical, or experimental. In cases where there seemed to be overlap into more than one category, the category has been chosen which describes the dominant or key features of the paper. The majority of the papers chosen for detailed review are those describing theoretical development or application.

2.1 Survey Papers

Ashley, H.: Unsteady Subsonic and Supersonic Inviscid Flow; AGARD CP-227, Unsteady Aerodynamics, September 1977.

- o 32 pages, 21 figures, 106 references
- o Discussion of analysis of time-dependent inviscid external flows over shapes of interest. Formulation of mathematical problem for velocity potential where arbitrary motions are emphasized. Methods of solution are summarized.

Ballhaus, W. F.: Some Recent Progress in Transonic Flow Computation; Von Karman Institute for Fluid Dynamics, Lecture Series 87, Computational Fluid Dynamics, March 1976.

- o 116 pages, 56 figures, 71 references
- o Reviews development of methods for steady three-dimensional flows about wing and wing-fuselage configurations, unsteady two dimensional flows, separated turbulent flows, the finite volume method and airfoil design by numerical optimization.

Jameson, A.: Transonic Flow Calculations; Von Karman Institute for Fluid Dynamics, Lecture Series 87, Computational Fluid Dynamics, March 1976.

- o 84 pages, 28 figures, 80 references
- o Reviews development of numerical solution techniques for full potential and transonic small disturbance equations for steady flow.

McCroskey, W. J.: Prediction of Unsteady Separated Flow on Oscillating Airfoils; AGARD-Lecture Series 94 Three Dimensional and Unsteady Separation at High Reynolds Numbers, February 1978.

- o 8 pages, 11 figures, 34 references
- o Summary of techniques for predicting flows at high Reynolds numbers with large amounts of separation. These include:

  1) Discrete potential vortex
  2) Boundary layer methods
  3) The strong interaction approach
  4) Navier - Stokes equations
  5) Correlations of existing data
  6) Other methods

McCroskey, W. J.: Some Unsteady Separation Problems for Slender Bodies; AGARD-Lecture Series 94, Three Dimensional and Unsteady Separation at High Reynolds Numbers, February 1978.

- o 11 pages, 16 figures, 24 references
- o Summary of prediction techniques for unsteady flow over wings and rotating blades. Features of unsteady separated flows that are not simple extensions of quasi-steady flows are discussed.

Mykytow, W. J.: A Brief Overview of Transonic Flutter Problems; AGARD CP-226, Unsteady Airloads in Separated and Transonic Flow, April 1977.

- o 11 pages, 12 figures, 14 references
- o Introduction to Transonic Unsteady Aerodynamics for Aeroelastic Phenomena session. Reviews historical flutter incidents, trends for straight and swept wings, data for conventional vs. supercritical airfoils, wind tunnel wall effects, trends with stores and external tanks, and some nonlinear phenomena.

Mykytow, W. J., and Olsen, J. J.: A Resume of Agard SMP Meeting on Transonic Unsteady Aerodynamics; AGARD-CP-227, Unsteady Aerodynamics - Ottawa, Canada, September 1977.

- o 20 pages, 21 figures, 9 references, 2 tables
- o Summary of specialists meeting on "Unsteady Airloads in Separated and Transonic Flow" at meeting of SMP of Agard-Lisbon, Portugal, April 1977. Outlines mutual needs and interests between aeroelasticians and aerodynamics.

Tijdeman, H.: Remarks of the Transonic Flow Around Oscillating Airfoils; AGARD-CP-227 Unsteady Aerodynamics, September 1977.

- o 52 pages, 30 figures
- o Review of recent experimental and numerical results (graphical material only)

2.2 Theoretical Papers

Baldwin, B. S., and Lomax, H.: Thin Layer Approximation and Algebraic Model for Separated Turbulent Flows; AIAA Paper 78-257, 16th Aerospace Science Meeting, January 1978.

- o 8 pages, 11 figures, 13 references
- o Basic Equations: 2 D thin layer equations Navier-Stokes, algebraic turbulence model
- o Coordinate System(s): Transformed, Body fitted, Stretched
- o No. Mesh Points: *64 x 36 and 77 x 36
- o Boundary Conditions: No slip
- o Algorithm: Implicit approximate factorization
- o Computation Times: 1400 - 6900 sec, on CDC 7600
- o Examples: Garbedian-Korn Airfoil, $M = .756$, $= 2.66$, $Re = 21 \times 10^6$; 18% Circular Arc, $M = .783$, $\alpha = 0$, $Re = 11 \times 10^6$

* For 2-D papers, the mesh dimensions are given for streamwise and vertical directions. For 3-D papers, the mesh dimensions are given for streamwise, spanwise, and vertical directions. If total number of mesh points is given, individual directions were not available.

Ballhaus, W. F., and Bailey, F. R.: Numerical Calculation of Transonic Flow About Swept Wings; AIAA Paper 72-677; 5th Fluid and Plasma Dynamics Conf., July 1972.

- o 10 pages, 11 figures, 13 references
- o Basic Equations: 3-D Steady small disturbance
- o Coordinate System(s): Stretched, Sheared, 3-D Cartesian
- o No. Mesh Points: 68 x 30 x 49
- o Boundary Conditions: Steady wing, Klunker Far-Field

o Algorithm: Relaxation

o Computation Times: 4-6 hours, IBM 360/67

o Examples: 23.75o Swept const. chord wing; C141 Airfoil section M = .752, α = 0o; M = .853, α = 0o, 2o

o Remarks: Basic paper for 3-D steady transonic flow by Bailey-Ballhaus method.

Ballhaus, W. F., and Lomax, H.: The Numerical Simulation of Low Frequency Unsteady Transonic Flow Fields; Proceedings 4th International Conference on Numerical Methods in Fluid Dynamics (Springer-Verlag, 1974), 1973.

o 7 pages, 6 figures, 2 references

o Basic Equations: 2-D Low frequency unsteady small disturbance

o Coordinate System(s): Cartesian

o Boundary Conditions: Solid airfoil, Impulsive start

o Numerical Algorithm: SLOR (steady); Semi-implicit time-marching

o Examples: Parabolic Arc (time-dependent thickness) M = .785, δ = .1; M = .80, k = .03

o Remarks: Preliminary work on unsteady transonic finite difference solutions

Ballhaus, W. F., and Steger, J. L.: Implicit Approximate - Factorization Schemes for the Low-Frequency Transonic Equation: NASA TM X-73,082, November 1975.

o 41 pages, 17 figures, 12 references

o Basic Equations: 2-D Low frequency unsteady small disturbance

o Coordinate System(s): Stretched Cartesian

o No. Mesh Points: Typically 80 x 80

o Boundary Conditions: Low frequency, $\phi_x = 0$ downstream, $\phi = 0$ elsewhere

o Numerical Algorithm: ADI

o Examples: Pulsating airfoil

o Remarks: Preliminary feasibility study only

Ballhaus, W. F., and Goorjian, P. M.: Implicit Finite Difference Computations of Unsteady Transonic Flows About Airfoils, Including the Treatment of Irregular Shock Wave Motions, AIAA Paper 77-205, Los Angeles, California, January 24-26, 1977.

o	10 pages, 9 figures, 17 references	
o	Basic Equations:	2-D, low frequency unsteady small disturbance
o	Coordinate System(s):	Stretched Cartesian
o	No. Mesh Points:	99 x 79
o	Boundary Conditions:	Time accurate, small disturbance, low-frequency
o	Numerical Algorithm:	Fully implicit approximate factorization (ADI)
o	Computation times:	8 sec per cycle of oscillation on CDC7600
o	Examples:	1. Oscillatory plunging airfoil (no designation given) - comparison with linear theory; M = 0.7, 0.8, 0.9; 0 < k < 0.4 2. NACA 64A006, k = 0.1, 0.8 M < 0.9 - pitching oscillation 3. NACA 64A006, trailing edge flap i) k = 0.064, M = 0.80 ii) k = 0.234, M = 0.875 iii) k = 0.179, M = 0.852

Ballhaus, W. F., and Goorjian, P. M.: Efficient Solution of Unsteady Transonic Flows About Airfoils, AGARD Conference Proceedings No. 226, April 1977.

o	11 pages, 9 figures, 7 references	
o	Basic Equations	2-D low frequency unsteady small disturbance
o	Coordinate System(s):	Stretched Cartesian
o	No. Mesh Points:	99 x 79
o	Boundary Conditions:	Oscillating airfoil, oscillating .25c flap; free response
o	Numerical Algorithm:	Time-marching ADI
o	Computation Times:	8 sec per cycle of oscillation on (CDC 7600)

- o Examples: 65A006 M = .875, .854, .822
  k = .234, .179, .248

- o Remarks: Compares results with Tijdeman's data for oscillating control surface, and solves one degree of freedom flutter problem for various levels of damping.

Ballhaus, W. F., Jameson, A., and Albert, J.: Implicit Approximate-Factorization Schemes for the Efficient Solution of Steady Transonic Flow Problems, Paper at AIAA Computational Fluid Dynamics Meeting, (also NASA TMX 73-202), June 1977.

- o 8 pages, 10 figures, 20 references
- o Basic Equations: 2-D steady small disturbance
- o Coordinate Systems(s) Variable mesh cartesian
- o No. Mesh Points: 128 x 32; 43 x 32; 22 x 16
- o Boundary Conditions: Free jet, free air; steady airfoil
- o Numerical Algorithm: Approximate factorization
- o Examples: 10% parabolic M = .84, .90
  Korn airfoil M = .75 α = .5, 1.0
- o Remarks: Shows that AF scheme is approximately 10 times as fast as SLOR for similar results. (NASA TMX 73-202 version includes only 10% parabolic arc example)

Ballhaus, W. F., Goorjian, P. M., and Yoshihara, H.: Unsteady Force and Moment Alleviation in Transonic Flow, AGARD Conference Proceedings No. 227, Paper 14, September 1977.

- o 10 pages, 15 figures, 3 references
- o Basic Equations: 2-D low frequency unsteady small disturbance
- o Coordinate System(s): Stretched Cartesian
- o Boundary Conditions: Pitch oscillations, leading & trailing edge flap oscillations
- o Numerical Algorithm: Time dependent ADI
- o Examples: NACA 64A006 with 10% LE and TE flaps
  M = .85 25% LE and 15% TE flaps
  10% chord bump

o Remarks: Application of Ballhaus - Goorjian method to demonstrate possibilities of lift and moment cancellation by control surface deflections.

Ballhaus, W. F., and Goorjian, P. M.: Computation of Unsteady Transonic Flows by the Indical Method, J. AIAA, Vol. 10, No. 2, (also AIAA Paper 77-447), February 1978.

- o 8 pages, 10 figures, 12 references
- o Basic Equations: 2-D low frequency unsteady transonic small disturbance
- o Coordinate System(s): Cartesian
- o Boundary Conditions: Solid airfoil, indicial and sinusoidal motion, free response
- o Numerical Algorithm: ADI following steady SLOR
- o Examples: NACA 64A006 M = .8, .85, .87, .88
NACA 64A010 M = .8
- o Remarks: Compares time integration and indicial method results for sinusoidal motions and step function motions. Also solves one degree of freedom flutter equation by time integration with various values of damping, demonstrating subcritical, neutrally stable, and unstable dynamic behavior.

Boppe, C. W.: Calculation of Transonic Wing Flows by Grid Embedding, AIAA Paper 77-207; 15th Aerospace Sciences Meeting, January 1977.

- o 11 pages, 17 figures, 17 references
- o Basic Equations: Modified 3-D steady small disturbance
- o Coordinate System(s): Cartesian course, transformed Cartesian fine grids
- o No. Mesh Points: 51 x 26 x 31
- o Boundary Conditions: Steady wing, free field
- o Numerical Algorithm: Relaxation (alternating course & fine sweeps)
- o Computation Times: 10 min, CYBER 175

o Examples: Airfoils: NACA 63A006 M = .9 α = 1o
Wings: AR = 4, const chord 35o swept (NACA 63A006)
M = .9 α = 3
ONERA M6, M = .84 α = 3
RAE wing A M = .9 α = 1
TACT 1 wing M = .85

o Remarks: Extends Bailey-Ballhaus method by including a fine grid and adding additional spanwise terms for swept shock capture.

Boppe, C. W.: Computational Transonic Flow About Realistic Aircraft Configurations, AIAA Paper 78-104 16th Aerospace Sciences Meeting, January 16-18, 1978, .

o 10 pages, 19 figures, 14 references

o Basic Equations: 3 D transonic small disturbance with additional terms for swept wings

o Coordinate System(s): Three grid system: Fine body grid, wing grid, and global coarse grid.

o Boundary Conditions: Exact on body and linearized on wing

o Numerical Algorithm: Relaxation method with upwind differencing for hyperbolic points

o Computation Times: 45 minutes on IBM 370, 15 min. on CDC CYBER 175

o Examples: Two wing body combinations

o Remarks: Good comparison with experiment.

Burstein, S. and Mirin, A.: Time Dependent Calculations for Transonic Flow, 3rd International Conference on Numerical Methods in Fluid Mechanics, July 1972.

o 12 pages, 2 figures, 10 references

o Basic Equations Unsteady Euler

o Coordinate System(s): Mapped polar coordinates

o No. Mesh Points: 15 x 80

o Boundary Conditions: Exact

o Numerical Algorithm: Time integration

o Computation Times: 1/2 hour on CDC 7600

o Examples: Ellipse, and NAE airfoil

Caughey, D. A., and Jameson, A.: Numerical Calculation of Transonic Potential Flow About Wing-Body Combinations, AIAA Paper 77-677, 10th Fluid & Plasmadynamics Conf, June 1977.

o	8 pages, 7 figures, 29 references	
o	Basic Equations	3 D steady full potential
o	Coordinate System(s):	Transformed Cartesian
o	No. Mesh Points:	96 x 16 x 16
o	Boundary Conditions:	Steady wing (exact geometry)
o	Numerical Algorithm:	Rotated difference relaxation
o	Computation Times:	7 minutes on CDC 7600
o	Examples:	ONERA M6 on circular fuselage M = .839, α = 3.07o ONERA M6 on area-ruled fuselage M = .839, α = 3.07o
o	Remarks:	Describes organization of computer code for large 3-dimensional problems. Extension of Jameson full-potential 3-D code.

Chen, A. W., Dickson, L. J., and Rubbert, P. E.: A Far Field Matching Method for Transonic Computations, AIAA Paper 77-203, 15th Aerospace Sciences Meeting, January 1977.

o	7 pages, 9 figures, 10 references	
o	Basic Equations	2-D & 3-D steady small disturbance
o	Coordinate System(s):	Cartesian
o	Boundary Conditions:	Steady airfoil, wing; new far field condition based on 1st and 2nd order panel methods
o	Numerical Algorithm:	Relaxation
o	Computation Times:	3-D; 800-1300 CP sec on CDC CYBER 175
o	Examples:	2-D asymmetric 6% parabolic M = .77 α = 0 3-D AR = 6 rect, NACA 0012 M = .82 α = 0
o	Remarks:	Modification of Murman-Cole (2-D) and Bailey-Ballhaus (3-D) for new far-field condition; comparison with Klunker.

Cunningham, A. M. Jr.: An Oscillatory Kernnel Function Method for Lifting Surfaces in Mixed Transonic Flow, AIAA Paper 74-359, AIAA/ASME/SAE 15th Structure, Structural Dynamics and Materials Conference, April 1974.

- o 11 pages, 11 figures 12 references
- o Basic Equations — downwash-pressure function integral equation
- o Coordinate System(s): — Not finite difference solution
- o No. Mesh Points: — 24 or 33 panels
- o Boundary Conditions: — Unsteady, general frequency
- o Numerical Algorithm: — No details
- o Computation Times: — 1 min. IBM 370/155
- o Examples: — 1. TND-344 rectangular wing AR = 3,M = 0.90, k = 0.13
  2. Trapezoidal wing of Becker M = 0.937, k = 0.218, $\alpha = 0$ Also M = 0.997, k = 0.207
  3. Trapezoidal wing of Becker, M = 0.942, k = 0.386, $\alpha = 0$ with oscillating aileron
  4. TND-344 rectangular wing, R = 3, steady M = 0.9, 1.0

Dowell, E.: A Simplified Theory of Oscillating Airfoils in Transonic Flow: Review and Extension, AIAA Dynamic Specialists Conference, March 1977.

- o 42 pages, 12 figures, 30 references
- o Basic Equations — 2 D unsteady transonic small disturbance equation with ϕ_{tt} term.
- o Coordinate System(s): — Cartesian
- o Remarks: — Analytic study related to local linearization concept. Good qualitative results.

Fung, K. Y., Yu, N. J., and Seebass, R.: Small Unsteady Perturbations in Transonic Flows, AIAA Paper 77-675, AIAA 10th Fluid & Plasmadynamics Conference, June 1977.

- o 12 pages, 10 figures, 18 references
- o Basic Equations — Low frequency, time linearized small disturbance equation
- o Coordinate System(s): Stretched Cartesian
- o Boundary Conditions: low freq; $\phi_x = 0$ downstream; $\phi = 0$ elsewhere
- o Numerical Algorithm: ADI/shock fitting
- o Examples: NACA 64A006 in pitch

Hafez, M. M., Murman, E. M., and South, J. C.: Artificial Compressibility Methods for Numerical Solution of Transonic Full Potential Equation, AIAA Paper 78-1148, July 1978.

- o 9 pages, 11 figures, 16 references
- o Basic Equations — 2 D full potential
- o Coordinate System(s): Cartesian with velocity oriented differencing
- o Boundary Conditions: Not discussed, probably similar to Jameson
- o Numerical Algorithm: Jamesons SOR, ADI and Explicit using Star computer. Damping added by modifying density.
- o Computation Times: ADI 300 cycles in 38 seconds on CYBER 175, 3000 cycles in 14 seconds on Star.
- o Examples: Circular cylinder and parabolic arc.
- o Remarks: Tests 3 different finite difference solution methods on a vector computer (CDC STAR 100).

Henne, P. A., and Hicks, R. M., Transonic Wing Analysis Using Advanced Computational Methods, AIAA Paper 78-105, 16th Aerospace Science Meeting, January 1978.

- o 9 pages, 19 figures, 9 references
- o Basic Equations: 3-D steady full potential; 3-D steady small disturbance
- o Coordinate System(s): Stretched cartesian
- o Boundary Conditions: Solid wing; small disturbance & exact surface
- o Numerical Algorithm: SOR
- o Examples:
  1. AR = 10, RECT (NACA 0010) M = .75, .85, α = 0
  2. AR = 6.33o swept (NACA 64-212) M = .6, .85 α = 4o
  3. AR = 7.32o swept supercritical (14%) M = .84, α = 1.85o
  4. AR = 7.32o swept supercritical (14%) - modified M = .84 α = 2o
- o Remarks: Compares results of Bailey-Ballhaus, Boppe, and Jameson-Caughey for transport-type wings, concludes full potential gives substantially better answers than small-disturbances.

Holst, T. L.: An Implicit Algorithm for the Conservative Transonic Full Potential Equation Using An Arbitrary Mesh, AIAA Paper 78-113, 11th Fluid & Plasmadynamics Conference, July 1978.

- o 12 pages, 8 figures, 19 references
- o Basic Equations: 2-D steady full potential
- o Coordinate System(s): Numerically generated conformal mesh
- o No. Mesh Points: 149 x 28
- o Boundary Conditions: Exact steady on airfoil surface
- o Numerical Algorithm: Implicit approximate factorization
- o Computation Times: 6 sec CDC 7600
- o Examples:
  NACA 0012 M = .63, .75 α = 2
  NACA 64A410 M = .72 α = 0
  75-06-12 M = .75 α = .12
- o Remarks: Shows substantial decrease in computation time over line overrelaxation schemes. Describes techniques for numerical mesh generation.

Isogai, K.: Unsteady Transonic Flow Over Oscillating Circular - Arc Airfoils, AIAA Paper 74-360 AIAA/ASME/SAE 15th Structures, Structural Dynamics, & Materials Conference, April 1974.

- o 11 pages, 11 figures, 16 references
- o Basic Equations — 3-D small disturbance, general frequency, potential integral equation; kernel function assumed with harmonic time dependence linearized unsteady criterion
- o Coordinate System(s): Cartesian
- o Boundary Conditions: High frequency, small disturbance on body
- o Numerical Algorithm: Gaussian Quadrature
- o Examples:
  1. Steady circular arc -6% thick - M = 1.011, $\alpha = 0^o$ (2-D)
  2. Circular arc, M = 1.0, pitch about leading edge
     $0 < k < 1.0$
     t/c = 0.025, 0.05, 0.10   2-D
  3. circular arc, M = 1.0, k = 0.10
     t/c = 0.025, 0.10
  4. circular arc, AR 2.52, M = 1.2, k = 1.0, t/c= 0.025
     and k = 2.3, t/c= 0.10

Isogai, K.: Approximate Method for Calculating Aerodynamic Loadings on an Airfoil Oscillating in High Subsonic Flow, Technical Report of National Aerospace Laboratory, NAL TR-455T, May 1976.

- o 11 pages, 7 figures, 14 references
- o Basic Equations — 2 D linearized small distrubance
- o Coordinate System(s): Cartesian
- o Boundary Conditions: Linearized
- o Numerical Algorithm: Kernel function method with numerical integration and a simple approximation of the mean steady flow
- o Examples: NACA 64A006 airfoil with quarter chord oscillating flap, and complete airfoil oscillating in pitch about center.
- o Remarks: Good agreement with experimental results.

Isogai, K.: Numerical Study on Unsteady Transonic Flow over Oscillating Airfoils Using the Full Potential Equation, NASA TP-1120, April 1978.

- o 59 pages, 21 figures, 9 references
- o Basic Equations: 2-D, unsteady full potential
- o Coordinate System(s): non-uniform Cartesian
- o Numerical Algorithm: Explicit time marching
- o Examples:

  NACA 64A006
  1. steady, M = 0.875 $\alpha = 0$
  2. 1/4 chord flap oscillation, M = 0.875, k = 0.234, $\beta = 1^o \sin \omega t$.
  3. steady, M = 0.860, $\alpha = 0^o$
  4. 1/4 chord flap oscillation, M = 0.86, k = 0.234, $\beta = 1^o \sin \omega t$
  5. pitching, M = 0.71, k = 0.10, $\alpha = 1^o \sin \omega t$
  6. pitching, M = 0.70, k = 0.10, $\alpha = 1^o \sin \omega t$
  7. pitching, M = 0.68, k = 0.10, $\alpha = 1^o \sin \omega t$

  70-10-13 supercritical
  1. pitching, M = 0.68, k = 0.10, $\alpha = 1^o + 1^o \sin \omega t$

  79-03-12 supercritical
  1. steady, M = 0.79, $\alpha = 0^o$
  2. pitching, M = 0.75, k = 0.30, $\alpha = 1^o \sin \omega t$,
  3. pitching, M = 0.75, k = 0.10, $\alpha = 1^o \sin \omega t$,
  4. steady, M = 0.75, $\alpha = 0^o$
  5. pitching, M = 0.70, k = 0.10, $\alpha = 1^o \sin \omega t$,

  NACA 0012
  1. pitching, M = 0.79, k = 0.10, $\alpha = 1^o \sin \omega t$
  2. pitching, M = 0.70, k = 0.10, $\alpha = 1^o \sin \omega t$

- o Remarks: This report is a summary of results, no theoretical development or numerical details provided.

Jameson, A., and Caughey, D. A.: Numerical Calculation of the Transonic Flow Past a Swept Wing, ERDA Research and Development Report, Mathematics and Computing, report no. COO-3077-140, June 1977.

- 93 pages, 14 figures, 18 references
- Basic Equations: 3 D steady state full potential
- Coordinate System(s): Swept coordinates aligned with the leading edge. Nearly conformal mapping in streamwise cross sections.
- No. Mesh Points: Large number possible. Program uses out of core solver.
- Boundary Conditions: Exact
- Numerical Algorithm: Row relaxation, with flow oriented differencing and upwind differencing at supersonic points. Uses coarse and fine grids. Non-conservative differencing.
- Computation Times: No times presented
- Examples: Good agreement with measurements on ONERA wing and Douglas wing.
- Remarks: Complete program listing given.

Klineberg, J. M., and Steger, J. L.: Calculation of Separated Flows at Subsonic and Transonic Speeds, Proc. 5th Int. Conf. Num. Methods Fluid Dynamics, June 1976, Springer-Verlag.

- 9 pages, 8 figures, 7 references
- Basic Equations: 2 D dimensional small disturbance equations in velocity components. Integral boundary layer equations.
- Coordinate System(s): Cartesian
- No. Mesh Points: 2300 to 3800
- Boundary Conditions: Linearized
- Numerical Algorithm: Standard over relaxation for inviscid equations, Runge Kutta for viscous equations
- Computation Times: Less than 30 min of IBM 360-67
- Examples: Flow over circular arc airfoil

Lee, K. D., Dickson, L. J., Chen, A. W., and Rubbert, P. E.: An Improved Matching Method for Transonic Computations, AIAA Paper 78-1116, 11th Fluid & Plasmadynamics Conference, July 1978.

- o 5 pages, 7 figures, 4 references

o Basic Equations	3 D transonic small disturbance; 3 D linearized
o Coordinate System(s):	Stretched Cartesian near-field finite element mid-field singularities on far field
o No. Mesh Points:	9072 to 35,840
o Boundary Conditions:	Solid airfoil; midfield matching; panel method far field
o Numerical Algorithm:	Relaxation; finite element
o Computation Times:	231 to 749 CP sec (CDC 7600)
o Examples:	Rectangular wing AR = 6 NACA 0012 M = .82
o Remarks:	Adds finite-element mid field representation to far field approach described in Chen, et. al. (1977).

Levy, J. J. Jr.: An Experimental and Computational Investigation of the Steady and Unsteady Transonic Flow Field About an Airfoil in a Solid Wall Test Channel, AIAA Paper 77-678, 10th Fluid and Plasmadynamics Conference, June 1977.

- o 11 pages, 10 figures, 11 references

o Basic Equations	2 D unsteady compressible turbulent Navier-Stokes
o Coordinate System(s):	Conformal about airfoil
o No. Mesh Points:	78 x 35
o Boundary Conditions:	No slip on airfoil surface, flow tangency on wind tunnel walls, no gradients downstream
o Numerical Algorithm:	Diewert code for Navier Stokes equations
o Examples:	1. Korn- Garabedian airfoil, $M = 0.750$, $\alpha = -1.59°$, $Re = 21 \times 10^6$ 2. 18% thick circular arc, $Re = 11 \times 10^6$, $\alpha = 0$ $M = 0.783$, 0.720, 0.754

Liu, D. D., and Winther, B. A.: Towards a Mixed Kernel Function Approach for Unsteady Transonic Flow Analysis, AGARD-CCP-227 Unsteady Aerodynamics, September 1977.

- o 17 pages, 12 figures, 49 references
- o Basic Equations: 3-D unsteady linearized small disturbance harmonic decomposition
- o Coordinate System(s): Cartesian
- o No. Mesh Points: 10 x 9 panels per semi-wing
- o Boundary Conditions: linearized on panel
- o Numerical Algorithm: Gaussan Quadrature of "transonic" (only subsonic and supersonic cases are considered) kernel function
- o Examples: Rectangular unswept wing - aspect ratios of 2, 3.6, 4
M = 0, 5/3,
M = 0.24, k = 0.47

Lomax, H., Bailey, F. R., and Ballhaus, W. F.: On the Numerical Simulation of Three Dimensional Transonic Flow With Application to the C-141 Wing, NASA TND-6933, August 1973.

- o 50 pages, 18 figures, 19 references
- o Basic Equations: Modified 3-D steady small disturbance
- o Coordinate System(s): Sheared, stretched Cartesian
- o No. Mesh Points: 68 x 23 x 49: 82 x 49 x 49
- o Boundary Conditions: Steady wing, free field
- o Numerical Algorithm: Relaxation
- o Examples: C-141 wing (AR = 8, sweep = 25.6o)
M = .825
- o Remarks: Develops modified transonic small disturbance equation for improved capture of swept shocks compares results of basic Bailey-Ballhaus method with wind tunnel and flight test data.

Magnus, R. J.: Computational Research on Inviscid, Unsteady, Transonic Flow Over Airfoils - Final Report, Office of Naval Research (Code 438) Dept. of the Navy Report no. CASD/LVP 77-010, January 1977.

- o 67 pages, 21 figures, 7 references
- o Basic Equations — 2 D unsteady Euler
- o Coordinate System(s): Coordinate system fixed on body
- o No. Mesh Points: Approximately 6,000
- o Boundary Conditions: Exact on mean airfoil surface
- o Numerical Algorithm: Explicit time-machining
- o Computation Times: As long as 6 to 7 hours on some examples. Not a production program
- o Examples: NACA 64A410 oscillating in pitch

Magnus, R., and Yoshihara, H.: The Transonic Oscillating Flap, AIAA Paper 76-327; 9th Fluid and Plasma Dynamics Conference, July 1976.

- o 13 pages, 9 figures, 8 references
- o Basic Equations — 2 D unsteady Euler
- o Coordinate System(s): Multiple including airfoil-fitted system embedded in Cartesian mesh
- o No. Mesh Points: 5484
- o Boundary Conditions: Exact applied at mean location, .25 C flap includes viscous ramp at shock location
- o Numerical Algorithm: Explicit Time marching
- o Examples: NACA 64A006 M = .875 k = 0, .234
- o Remarks: Comparison with Tijdemann data demonstrates effects of viscous wedge approximation and aft specified pressures.

Magnus, R., and Yoshihara, H.: The Transonic Oscillating Flap, AGARD CP-226, Unsteady Airloads in Transonic and Separated Flow, April 1977.

- o 5 pages, 8 figures, 2 references
- o Basic Equations — 2 D unsteady Euler
- o Coordinate System(s): Multiple, including surface fitted
- o Boundary Conditions: Exact on mean surface, free field
- o Numerical Algorithm: Explicit time marching
- o Examples: NACA 64A006 w/ .25c flap, M = .854, .875, , .900 $\alpha = 0, \alpha = \pm 1$, k = .234,
- o Remarks: Adds aft pressure prescription to results of previous paper (AIAA 76-327).

Mason, W., Mackenzie, D. A., Stern, M. A., and Johnson, J. K.: A Numerical Three-Dimensional Viscous Transonic Wing-Body Analysis and Design Tool, AIAA Paper 78-101; 16th Aerospace Sciences, January 1978.

- o 16 pages, 11 figures, 42 references
- o Basic Equations — 3 D steady modified small disturbance equation
- o Coordinate System(s): Multiple embedded grids (stretched, swept Cartesian)
- o No. Mesh Points: 35,400 (maximum)
- o Boundary Conditions: Steady wing, free field
- o Numerical Algorithm: Relaxation
- o Computation Times: 10 min on CDC 7600
- o Examples: NACA 64A010 M = .84 α = 0
  M6 ONERA wing M = .92 α = 0
  NACA TND712 wing-body model M = .94 (RMA55B21)
  NACA wing-body model M = .94 (TND712)
  Advanced fighter M = .9 α = 7
  F-8 Supercritical wing M = .9, α = 3.5
- o Remarks: Extends Boppe method to include fuselage and viscous-inviscid interactions by including 3-D boundary layer.

Melnik, R. E., and Ives, D. G.: On Viscous and Wind-Tunnel Wall Effects in Transonic Flows Over Airfoils, AIAA Paper No. 73-660, July 1973.

o	16 pages, 8 figures, 12 references	
o	Basic Equations	2-D steady full potential
o	Coordinate System(s):	Cartesian
o	No. Mesh Points:	32 x 92
o	Boundary Conditions:	Exact
o	Numerical Algorithm:	Standard relaxation with upwind differencing at supersonic points.
o	Examples:	17 cases on same Korn supercritical airfoil
o	Remarks:	Relaxes Kutta conditions and uses measured lift to determine circulation.

Mirin, A. A., and Burstein, S.: Difference Methods for Transonic Flows About Airfoils, 4th International Conference on Numerical Methods in Fluid Dynamics, June 1974.

o	10 pages, 4 figures, 2 references	
o	Basic Equations	2-D unsteady Euler
o	Coordinate System(s):	Transformed polar
o	No. Mesh Points:	80 x 21
o	Numerical Algorithm:	Time maching to steady limit
o	Examples:	A Korn airfoil, an NAE airfoil, and a NACA 0012

Murman, E. M., and Cole, J. D.: Calculation of Plane Steady Transonic Flows, AIAA Journal, January 1971.

- o 8 pages, 12 figures, 14 references

o Basic Equations	2-D steady small disturbance
o Coordinate System(s):	Cartesian
o No. Mesh Points:	74 x 41, 148 x 71
o Boundary Conditions:	Linear on airfoil, doublet far-field
o Numerical Algorithm:	SOR - type dependent differencing
o Computation Times:	Typically 400 iterations - 30 minutes on IBM 360/44
o Examples:	Circular Arc, curved plate, K = 2.5, 2.3, 2.1, 1.8, 1.45, 1.15, (transonic similarity parameter) NLR 0.12 -0.70-0.00 K = 1.71, 1.82, 1.60
o Remarks:	Basic paper for relaxation method with mixed differencing.

Murman, E. M.: A Relaxation Method for Calculating Transonic Flows With Detached Bow Shocks, Proceedings of 3rd International Conference on Numerical Methods in Fluid Mechanics (Springer-Verlag, 1973), 1972.

- o 4 pages, 6 figures, 9 references

o Basic Equations	2-D steady small disturbance
o Coordinate System(s):	Stretched Cartesian
o No. Mesh Points:	2100 to 6700
o Boundary Conditions:	Steady airfoil; perforated wall, free air
o Numerical Algorithm:	Relaxation
o Computation Times:	.8 to 69 minutes IBM 360/67
o Examples:	Parabolic Arc, M = 1.011, 1.052, 1.083 NACA 4-digit, M = 1.10, 1.25
o Remarks:	Extension of basic Murman method to handle supersonic free stream.

Murphy, W. D., and Malmuth, N. D.: A Relaxation Solution For Transonic Flow Over Three-Dimensional Jet-Flapped Wings, AIAA Paper No. 76-98, January 1976.

- o 10 pages, 7 figures, 13 references
- o Basic Equations: 2-D steady small distrubance
- o Coordinate System(s): Stretched, sheared Cartesian
- o No. Mesh Points: 68 x 35 x 36
- o Boundary Conditions: Linearized on wing plane
- o Numerical Algorithm: Standard over-relaxation with fully conservative differencing
- o Examples: Rectangular wing, swept wing, tapered wing with ONERA section
- o Remarks: Comparison of calculated lift coefficients with experimental values show good agreement.

Nixon, D.: Calculation of Unsteady Transonic Flows Using The Integral Equation Method, AIAA Paper 78-13, AIAA 16th Aerospace Sciences Meeting, January 1978.

- o 11 pages, 4 figures, 13 references
- o Basic Equations: 2-D unsteady linearized small disturbance
- o Boundary Conditions: Linearized
- o Numerical Algorithm: Integral equation method with strained coordinates
- o Remarks: This is an analytic method which requires later numerical solution.

Rizzetta, D. P.: Transonic Flutter Analysis of Two-Dimensional Airfoil, AFFDL TM-77-64-FBR, July 1977.

- o 29 pages, 4 figures, 10 references
- o Basic Equations 2-D unsteady small disturbance
- o Coordinate System(s): Stretched Cartesian
- o Boundary Conditions: Plunge, pitch; free response (flutter)
- o Numerical Algorithm: Relaxation
- o Examples: NACA 64A010, M = .72, .80 $\alpha = 0^o, 1^o$
- o Remarks: Applications of STRANS, UTRANS programs (Traci et al).

Rizzetta, D. P.: A Comparative Study of Two Computational Methods for Calculating Unsteady Transonic Flows About Oscillating Airfoils, AFFDL TR-77-118, November 1977.

- o 36 pages, 11 figures, 23 references
- o Basic Equations 2-D unsteady small disturbance
- o Coordinate System(s): Stretched Cartesian
- o No. Mesh Points: 70 x 43; 99 x 79
- o Boundary Conditions: Pitch oscillation
- o Numerical Algorithm: Relaxation; unsteady ADI
- o Examples: NACA 64A010, M = .72, .82,k = .05, .2
- o Remarks: Compares results of frequency domain method (Traci, et al) with time marching (Ballhaus & Goorjian) for harmonic motion.

Rizzetta, D. P.: The Aeroelastic Analysis of a Two-Dimensional Airfoil in Transonic Flow, AFFDL-77-126, December 1977.

- o 45 pages, 22 figures, 22 references
- o Basic Equations — 2-D unsteady small disturbance
- o Coordinate System(s): Stretched Cartesian
- o No. Mesh Points: 99 x 79
- o Boundary Conditions: Pitch, plunge, flap oscillation, free response
- o Numerical Algorithm: Unsteady ADI
- o Computation Times: 20 minutes/1000 time steps CYBER 74
- o Examples: NACA 64A010 M = .72, .82
- o Remarks: Uses 3 Degree-of-Freedom equations with ADI method of Ballhaus and Goorjian for flutter analysis by time-integration.

Rose, W. C., and Seginer, A.: Calculation of Transonic Flow Over Supercritical Airfoil Sections, AIAA Paper 77-681, AIAA 10th Fluid and Plasma Dynamics Conference, Albequeue, N.W., June 1977.

- o 7 pages, 11 figures, 16 references
- o Basic Equations — 2-D Navier-Stokes
- o Coordinate System(s): Body fitted
- o No. Mesh Points: 300
- o Boundary Conditions: Exact
- o Numerical Algorithm: Navier Stokes solvers with turbulence model
- o Computation Times: 90 minutes on CDC 7600
- o Examples: NACA 64A010, M = .8

Kuo, S. Y., and Theisen, J. G.: Calculation of Unsteady Transonic Aerodynamics for Oscillating Wings with Thickness, NASA CR-2259, June 1975.

- o 51 pages, 12 figures, 46 references
- o Basic Equations: 3-D unsteady small disturbance, local linearization, harmonic decomposition
- o Coordinate System(s): Cartesian
- o No. Mesh Points: 25 boxes, 90 boxes
- o Boundary Conditions: Linearized
- o Examples:
  1. Biconvex rectangular wing, AR = 2, $\alpha = 0.521$, $0 < k < 1$ also $\alpha = 0$
  2. Biconvex delta wing, AR = 1.5, $0 < k < 1$ $\alpha = 0,\ 0.05,\ 0.10,\ 0.15$
  3. Bicovex delta wing AR = 1.44, $0 < k < 1$ $\alpha = 0.0944$
  4. Bicovex delta wing AR = 1.45, $0 < k < 1$ $\alpha = 0.06$
  5. Parabolic wing, AR = 1.5, $o < k < 1$, $\alpha = 0,\ 0.3$

Schmidt, W., Rohlfs, S., and Vanino, R.: Some Results Using Relaxation Methods for Two- and Three-Dimensional Transonic Flows, 4th International Conference.

- o 9 pages, 7 figures, 11 references
- o Basic Equations: 3-D steady small disturbance
- o Coordinate System(s): Cartesian
- o No. Mesh Points: 46 x 12 x 12
- o Boundary Conditions: Linearized
- o Numerical Algorithm: Upwind differencing at hyperbolic points. Standard relaxation.
- o Computation Times: Approximately 7 minutes CPU on IBM 370/155
- o Examples: RAE wing C at M = .95, ONERA wing M6, PT3 wing body model wing.

Seebass, A. R., Yu, N. J., and Fung, K-Y: Unsteady Transonic Flow Computations, AGARD Fluid Dynamic Panel Symposium on Unsteady Aerodynamics, September 1977.

o	18 pages, 9 figures, 31 references	
o	Basic Equations	2 D unsteady time linearized small disturbance
o	Coordinate System(s):	Coordinates Mapping infinite region into rectangle
o	No. Mesh Points:	101 x 82
o	Boundary Conditions:	Linearized
o	Numerical Algorithm:	ADI with shock fitting for the time dependent equation
o	Computation Times:	5 seconds per time step, 60 to 190 time steps/cycle
o	Examples:	NACA 64A006 airfoil, oscillating 1/4 chord flap, and oscillating pitching motion.
o	Remarks:	Good comparison of linearized time dependent results with direct solution of nonlinear equation.

South, J. C.: Comments on Difference Schemes for the Three-Dimensional Transonic Small Disturbance Equation for Swept Wings, NASA TMX-71980, July 1976.

o	9 pages, 0 figures, 4 references	
o	Basic Equations	Various forms of 3-D steady small disturbance
o	Remarks:	Discusses the various forms of the equation and implications on accuracy and stability.

Steger, J. L.: Implicit Finite Difference Simulation of Flow About Arbitrary Geometries with Application to Airfoils, AIAA Paper No. 77-665, 10th Fluid and Plasmadynamics Conference, June 1977.

- o 14 pages, 12 figures, 32 references
- o Basic Equations: 2 D unsteady Euler equations, or "thin layer" Navier-Stokes
- o Coordinate System(s): Transformed mapped, body fitted, stretched
- o No. Mesh Points: 77 x 27 - inviscid; 71 x 33 - viscous
- o Boundary Conditions: Exact time dependent on time accurate boundary
- o Numerical Algorithm: Implicit approximate factorization
- o Computation Times: 0.75 sec/time step on 7600
- o Examples:
  1. inviscid NACA 0012, M = 0.63, .75 $\alpha = 2^o$
  2. inviscid, linear NACA 64A010, M = .8 $\alpha = 1^o \sin \omega t$
  3. viscous, linear NACA 0012, $\alpha = 0^o$, M = 0.2, Re = 10^4
  4. viscous 18% biconvex, M = 0.75, α = 0, Re = 11 x 10^6, turbulent
  5. viscous, 18% biconvex, M = 0.783, α = 0, buffet case

Traci, R. M., Farr, J. L., and Albano, E.: Perturbation Method for Transonic Flows About Oscillating Airfoils, AIAA Paper 75-877, AIAA 8th Fluid and Plasmadynamics Conference, Hartford, Conn., June 1975.

- o 12 pages, 14 figures, 22 references
- o Basic Equations: 2 D Low frequency unsteady time linearized small disturbance equation
- o Coordinate System(s): Cartesian, stretched grid
- o No. Mesh Points: 50 x 50 approx
- o Boundary Conditions: Low freq BC's
- o Numerical Algorithm: SLOR
- o Examples: NACA 64A006, 64A410 at various ω, M, plunge, pitch + oscillating modes
- o Remarks: Also AIAA J. Vol. 14 No. 9, September 1976.

Weatherill, W. H., Ehlers, T. E., and Sebastian, J. D.: On the Computation of the Transonic Perturbation Flow Field Around Two- and Three-Dimensional Oscillating Wings, AIAA Paper No. 76-99, 14th Aerospace Sciences Meeting, January 1976.

o	13 pages, 7 figures, 20 references	
o	Basic Equations	2 D and 3 D unsteady time linearized small disturbance
o	Coordinate System(s):	Non-uniform Cartesian
o	No. Mesh Points:	2-D: 25 x 16, 34 x 28, 42 x 30 3-D: 25 x 19 x 20
o	Boundary Conditions:	Small disturbance, unsteady; far field doublet
o	Numerical Algorithm:	SOR
o	Computation Times:	7-8 sec per iteration 8-9 sec per for field update 180 iterations for convergence
o	Examples:	1. 2-D flat plate, M = 0.875, pitching oscillation, quasi-steady (K=0) also K = 0.06 2. AR = 5 rectangular wing, NACA 64A006, M = 0.875, pitching oscillation, K = 0.06, AR = 5.

Weatherill, W. H., Sebastian, J. D., and Ehlers, F. E.: Application of a Finite Difference Method to the Analysis of Transonic Flow Over Oscillating Airfoils and Wings, AGARD Conference Proceedings No. 226, Paper No. 17, Unsteady Airloads in Separated and Transonic Flow, 1976.

o	13 pages, 13 figures, 17 references	
o	Basic Equations	2-D and 3-D small disturbances time linearized
o	Coordinate System(s):	Cartesian, stretched Cartesian
o	No. Mesh Points:	2-D: 28 x 20, 42 x 30 3-D: 44 x 32 x 26
o	Boundary Conditions:	Klunker, outgoing wave, porous wall, free jet, solid wall
o	Numerical Algorithm:	Row and column relaxation of linear unsteady part

o Computation Times: 2-D case 30 minutes CDC 6600

o Examples: 2-D - Flat plate oscillating in pitch $M = .9$, $k = .09, .3$
3-D - Rectangular wing (NACA 64A006 section) $M = .875$ $k = .06$ oscillating in pitch

o Remarks: Basic paper for 3-D frequency - domain method. Discusses instability problems for high frequency and possible resolution by direct solution.

2.3 Experimental Papers

Bergh, H., and Tijdeman, H.: Analysis of Pressure Distribution Measured on a Wing With Oscillating Control Surface in Two Dimensional High Subsonic and Transonic Flow, NLR-TR F 253, 1969.

- o 32 pages, 38 figures, 25 references

o Facility	National Aerospace Laboratory, Netherlands
o Test Section & Wall Conditions:	closed circuit wind tunnel, h = .55 m, w = .42 m, longitudinal slotted upper and lower walls
o Model(s):	2-D wing, control surface, NACA 65A006
o Mach Numbers:	0.5 to 1.02
o Motion Types:	Sinusoidal oscillation
o Frequencies:	30, 60, 90, 120, 150 Hz
o Measurements:	Detailed measurements of steady and unsteady surface pressures
o Remarks:	1. amplitude of oscillation was maximum of 3o 2. some discussion on wall interference

Ruhlin, C. L., and Sandford, M. C.: Experimental Parametric Studies of Transonic T-Tail Flutter, NASA TN-D 8066, December 1975.

- o 50 pages, 11 figures, 12 references

o Facility:	Langley transonic dynamics tunnel
o Test Section and Wall Conditions:	4.88-m2 test section = 16 ft. slotted walls
o Model(s):	1/13 size wide-body, multijet, cargo/transport with T-tail a. one tail had load nominal design stiffness for complete model b. one tail had 1/2 nominal design stiffness for only longitudinal tail
o Mach Numbers:	$0.7 < M < 1.0$
o Motion Types:	Flutter
o Frequencies:	$0 < f < 12 H_z$
o Measurements:	Dynamic pressures, flutter frequencies

Seegmiller, H. L., Marvin, J. G., and Levy, Jr., L. L.: Steady and Unsteady Transonic Flow, AIAA Paper 78-160, 16th Aerospace Sciences Meeting, January 1978.

o	14 pages, 16 figures, 20 references	
o	Facility:	NASA Ames high Reynolds No. channel
o	Test Section and Wall Conditions:	.28 m x 25 m (2-D section) contoured solid walls
o	Model(s):	18% circular arc airfoil
o	Mach Numbers:	.76, .79
o	Reynolds Numbers:	11×10^6
o	Motion Types:	Steady $\alpha = 0^o$
o	Measurements:	Mean velocity, turbulent stress, kinetic energy (Laser) surface pressures (steady & unsteady)
o	Remarks:	Compares flow field and surface pressure fluctuations due to shock induced separation with results from Navier-Stokes solutions.

Tijdeman, H., Schippers, P., and Persoon, A. J.: Unsteady Airloads on an Oscillating Supercritical Airfoil, AGARD CP-226 Unsteady Airloads in Transonic and Separated Flow, April 1977.

o	15 pages, 27 figures, 23 references	
o	Facility:	NLR pilot tunnel
o	Test Section and Wall Conditions:	.55 m x .42 m, slotted walls
o	Model(s):	NLR 7301 airfoil
o	Mach Numbers:	.5 to 1.0
o	Reynolds Number:	2.1×10^6
o	Motion Types:	Pitch oscillation
o	Frequencies:	10 Hz to 80 Hz
o	Measurements:	Unsteady pressures, force and moment coefficients
o	Remarks:	Compares results with finite difference calculations

Tijdeman, H.: Investigations of the Transonic Flow Around Oscillating Airfoils, (PhD Thesis), National Aerospace Laboratory (Netherlands) TR 77090-U , October 1977.

- 146 pages, 0 figures, 188 references
- Facility: NLR pilot tunnel
- Test Section and Wall Conditions: .55 m x 42 m, slotted walls
- Model(s): NACA 64A006, NLR 7301 airfoils
- Mach Numbers: .5 to 1.0
- Reynolds Numbers: 2.1 x 106
- Motion Types: Oscillations, control surface oscillations
- Frequencies: 10 Hz to 120 Hz
- Measurements: Unsteady & steady pressures, force and moment coefficients, shock patterns
- Remarks: Compares results with finite difference methods. Reviews status of transonic flow.

Section III. Summary Chart—Comprehensive Reference List

Author (date)	Type			Equations					Time-dependence		Geometry				Solution method					Data			
	Survey	Theoretical	Experimental	Navier-Stokes	Euler	Full potential	Small-disturbance	Linear	Steady	Unsteady	Airfoils	Control Surface	Wings	Wing-body	Relaxation	Time-marching	Finite element	Frequency expansion	Linear	Pressures	Forces, moments	Flutter	Wall effects
Ageev (1974)			●							●		●	●							●			
Albone (1974)		●					●		●		●												
Albone (1975)		●					●		●					●									
Andrew (1963)		●						●		●		●	●						●				
Ashley (1977)	●								●	●													
Bailey (1973)a		●					●		●				●	●	●								
Bailey (1973)b		●					●		●				●		●								
Bailey (1975)a		●					●		●		●		●		●								
Bailey (1975)b		●					●		●				●	●	●					●			
Balcerak (1958)			●							●			●									●	
Baldwin (1978)*		●		●						●	●					●							
Ballhaus (1972)*		●					●		●				●		●								
Ballhaus (1974)*		●					●			●	●					●							
Ballhaus (1975)a		●			●					●	●					●							
Ballhaus (1975)b*		●					●			●	●					●							
Ballhaus (1976)		●					●		●				●		●					●			
Ballhaus (1977)a*		●					●		●						●								
Ballhaus (1977)b*		●					●			●	●	●				●				●			
Ballhaus (1977)c*		●					●			●	●					●							
Ballhaus (1977)d*		●					●			●	●	●				●							
Baronti (1971)		●					●		●		●				●								
Beam (1974)		●		●						●	●					●							
Beam (1975)		●		●			●			●	●					●							
Becker (1969)			●										●							●			
Bergh (1967)*			●							●	●	●								●	●		
Bergh (1970)			●							●		●	●							●			
Berndt (1976)			●						●														●
Boppe (1977)*		●					●		●		●		●		●								
Boppe (1978)*		●					●		●		●		●	●	●								
Brady (1958)			●							●			●									●	
Burstein (1972)*		●			●					●	●					●							
Carlson (1974)		●				●			●		●				●								
Carlson (1975)		●				●					●				●								
Carlson (1976)a		●				●					●				●								
Carlson (1976)b		●				●					●				●								
Caughey (1977)*		●				●					●				●								

*Reviewed

Section III. Summary Chart—Comprehensive Reference List (Continued)

Author (date)	Type			Equations					Time-dependence		Geometry				Solution method					Data			
	Survey	Theoretical	Experimental	Navier-Stokes	Euler	Full potential	Small-disturbance	Linear	Steady	Unsteady	Airfoils	Control Surface	Wings	Wing-body	Relaxation	Time-marching	Finite element	Frequency expansion	Linear	Pressures	Forces, moments	Flutter	Wall effects
Chan (1975)		●					●			●	●						●						
Chan (1976)		●					●		●	●	●						●						
Chan (1977)		●				●				●	●						●						
Chen (1977)*		●					●	●	●						●				●				
Chu (1976)		●								●	●												
Chu (1977)		●								●	●												
Cole (1971)	●									●													
Cole (1975)	●						●																
Collins (1974)		●	●						●		●												
Cooper (1959)			●							●		●	●									●	
Cunningham (1973)		●						●		●			●						●				
Cunningham (1974)		●						●		●			●						●				
Cunningham (1976)a		●						●		●			●						●				
Cunningham (1976)b		●						●		●			●						●				
Cushman (1953)			●																				●
Delery (1976)			●						●		●												
Ehlers (1974)a		●					●			●			●					●					
Ehlers (1974)b		●					●			●			●					●					
Farmer (1976)			●							●			●									●	
Frey (1970)	●																						
Fung (1977)a		●					●			●	●							●					
Fung (1977)b*		●					●			●	●							●					
Gardner (1976)		●						●		●			●						●				
Hafez (1976)		●					●		●		●						●						
Hafez (1977)a		●					●		●		●				●								
Hafez (1977)b		●				●			●		●				●								
Hafez (1978)*		●				●			●		●				●								
Hall (1974)		●					●		●			●											
Hall (1976)a	●								●														
Hall (1976)b	●																						
Hedman (1977)		●					●		●				●		●								
Henne (1978)*		●				●	●		●				●		●								
Holst (1978)*		●				●			●		●				●								
Isogai (1974)*		●					●			●	●							●					
Isogai (1977)		●				●				●	●					●							
Isogai (1978)*		●				●				●	●				●								

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Section III. Summary Chart—Comprehensive Reference List (Continued)

Author (date)	Type			Equations					Time-dependence		Geometry				Solution method					Data			
	Survey	Theoretical	Experimental	Navier-Stokes	Euler	Full potential	Small-disturbance	Linear	Steady	Unsteady	Airfoils	Control Surface	Wings	Wing-body	Relaxation	Time-marching	Finite element	Frequency expansion	Linear	Pressures	Forces, moments	Flutter	Wall effects
Jameson (1976)		●				●			●				●		●								
Jameson (1977)*		●				●			●				●		●								
Karlsen (1976)		●			●				●		●					●							
Karlsson (1976)		●				●			●					●		●							
Khosla (1973)		●							●														
Kimble (1973)		●					●			●			●					●					
Kimble (1975)		●					●			●			●					●					
Kimble (1976)		●				●				●			●	●			●						
Klineberg (1976)		●		●					●		●					●							
Kordulla (1977)		●				●			●				●		●								
Krupp (1976)		●								●													
Landahl (1959)a		●						●		●		●	●						●				
Landahl (1959)b		●						●		●			●						●				
Landahl (1962)		●						●		●													
Landahl (1975)		●						●		●			●						●				
Laval (1974)		●														●							
Laval (1976)		●			●					●	●					●							
Lee (1978)*		●					●	●	●		●		●		●		●		●				
Lerat (1977)		●			●					●	●					●							
Levy (1977)*		●	●	●						●						●				●			
Loiseau (1967)			●							●												●	
Lomax (1971)		●							●		●				●								
Lomax (1973)*		●					●		●				●		●								
Magnus (1974)		●			●					●	●					●							
Magnus (1975)		●			●					●	●					●							
Magnus (1976)*		●			●					●	●	●				●							
Magnus (1977)a*		●			●					●	●					●							
Magnus (1977)b		●			●					●	●					●							
Magnus (1977)c		●			●					●	●	●				●							
Mason (1978)*		●					●		●					●	●								
McCroskey (1977)	●									●													
McCroskey (1978)a*	●									●													
McCroskey (1978)b*	●									●													
Meier (1974)	●									●													
Melnik (1973)*		●	●																				●
Mirin (1975)*		●			●				●							●							

*Reviewed

Section III. Summary Chart—Comprehensive Reference List (Continued)

Author (date)	Type			Equations					Time-dependence		Geometry				Solution method					Data			
	Survey	Theoretical	Experimental	Navier-Stokes	Euler	Full potential	Small-disturbance	Linear	Steady	Unsteady	Airfoils	Control Surface	Wings	Wing-body	Relaxation	Time-marching	Finite element	Frequency expansion	Linear	Pressures	Forces, moments	Flutter	Wall effects
Morchoise (1975)		●							●		●						●						
Moretti (1975)	●																						
Moretti (1976)	●																						
Murman (1971)*		●					●		●		●				●								
Murman (1972)*		●					●		●		●				●								
Murman (1977)		●					●		●		●												
Murphy (1977)*		●					●		●				●		●								
Mykytow (1977)a*	●																						
Mykytow (1977)b*	●																						
Naves (1975)		●							●					●			●						
Nazarenko (1972)			●							●			●							●			
Newman (1976)		●							●														
Nichols (1977)		●					●			●	●					●	●						
Nixon (1977)		●								●													
Nixon (1978)*		●								●													
Nieuwland (1973)	●																						
Oehmen (1973)		●							●	●													
Oehmen (1976)		●							●	●													
Olsen (1976)		●					●		●		●				●								
Olshanskii (1976)		●					●			●	●							●					
Phares (1976)		●			●				●		●						●						
Platzer (1972)	●																						
Reed (1976)			●																				●
Rizzetta (1977)a*		●					●			●	●					●							●
Rizzetta (1977)b*		●					●			●	●					●		●					
Rizzetta (1977)c*		●					●			●	●					●							●
Rizzi (1975)		●			●					●	●						●						
Rizzi (1976)		●			●					●			●				●						
Rodden (1976)	●																						
Rose (1977)*		●		●					●		●					●							
Rubesin (1976)		●	●	●						●	●					●				●			
Ruo (1974)a		●						●		●			●						●				
Ruo (1974)b		●						●		●			●						●				
Ruo (1975)*		●						●		●			●						●				
Savkar (1976)		●								●	●												
Schmidt (1975)*		●					●		●		●		●		●								

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Section III. Summary Chart—Comprehensive Reference List (Continued)

Author (date)	Type			Equations					Time-dependence		Geometry				Solution method					Data			
	Survey	Theoretical	Experimental	Navier-Stokes	Euler	Full potential	Small-disturbance	Linear	Steady	Unsteady	Airfoils	Control Surface	Wings	Wing-body	Relaxation	Time-marching	Finite element	Frequency expansion	Linear	Pressures	Forces, moments	Flutter	Wall effects
Schmidt (1976)		●					●		●				●	●	●								
Seebass (1974)		●							●														
Seebass (1976)		●					●		●		●				●								
Seebass (1977)*		●					●			●	●							●					
Seegmiller (1973)			●						●	●													
Seginer (1977)		●		●			●		●		●												
Sills (1968)		●							●		●					●							
Sills (1972)		●							●		●				●								
South (1976)a*		●					●		●						●								
South (1976)b		●					●		●		●				●								
Spreiter (1971)		●							●		●												
Spreiter (1975)	●																						
Spreiter (1976)	●																						
Stahara (1973)		●					●			●													
Stahara (1976)		●						●		●													
Steger (1973)		●			●				●														
Steger (1977)*		●								●	●					●							
Thiede (1976)		●				●			●		●												
Tijdeman (1973)a			●							●			●							●			
Tijdeman (1973)b			●							●	●	●								●			
Tijdeman (1975)a			●							●	●	●								●			
Tijdeman (1975)b			●							●	●	●								●			
Tijdeman (1976)a			●							●	●		●										
Tijdeman (1976)b			●							●	●									●			
Tijdeman (1976)c			●							●	●		●										
Tijdeman (1977)a*			●							●	●									●			
Tijdeman (1977)b*			●							●	●	●								●			
Tijdeman (1977)c			●							●	●	●								●			
Traci (1974)		●					●			●								●					
Traci (1975)		●					●			●	●		●					●					
Traci (1976)		●					●			●	●				●			●					
Triebstein (1969)			●							●			●							●			
Turbatu (1975)		●					●			●			●										
Turbatu (1976)		●					●			●			●										
Vandervooren (1975)		●					●			●					●								
Vanino (1975)		●							●					●	●								

*Reviewed

Section III. Summary Chart—Comprehensive Reference List (Continued)

	Type			Equations					Time-dependence		Geometry				Solution method					Data			
Author (date)	Survey	Theoretical	Experimental	Navier-Stokes	Euler	Full potential	Small-disturbance	Linear	Steady	Unsteady	Airfoils	Control Surface	Wings	Wing-body	Relaxation	Time-marching	Finite element	Frequency expansion	Linear	Pressures	Forces, moments	Flutter	Wall effects
Warming (1975)		●			●					●	●					●							
Warming (1976)		●			●					●	●					●							
Weatherill (1975)		●					●			●	●		●		●			●					
Weatherill (1976)*		●					●			●	●		●		●			●					
Weatherill (1977)*		●					●			●	●		●		●			●					
Wu (1974)		●								●	●												
Wu (1976)	●																						
Yoshihara (1973)	●																						
Yu (1975)		●							●														
Yu (1977)		●					●			●	●	●				●							
Albone (1974) b		●					●		●		●				●								
Ballhaus (1976) b	●																						
Beam (1976)		●			●											●							
Bland (1975)	●																						
Burdges (1973)			●								●												
Burdges (1974)			●								●												
Caradonna (1976)		●					●			●	●					●							
Chan (1974)		●					●		●		●						●						
Chan (1975) b		●					●		●		●						●						
Chan (1976) b		●					●		●		●						●						
Deiwert (1975)		●		●						●	●					●							
Deiwert (1976) a		●		●						●	●					●							
Deiwert (1976) b		●		●						●	●					●							
Dowell (1975)		●						●		●	●								●				
Dowell (1977)																							
Farr (1974)		●					●			●	●				●			●					
Farr (1975)		●					●			●			●		●			●					
Garner (1966)			●							●													●
Hafez (1977) c		●					●			●	●				●								
Hafez (1977) d		●					●			●	●				●								
Harris (1972)			●											●						●	●		
Holman (1975)		●					●		●	●	●							●					
Jameson (1974)		●				●			●		●		●		●								
Jameson (1977) b		●				●			●					●	●								
Keller (1978)		●					●		●		●				●	●							

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Author (date)	Type			Equations					Time-dependence		Geometry				Solution method					Data			
	Survey	Theoretical	Experimental	Navier-Stokes	Euler	Full potential	Small-disturbance	Linear	Steady	Unsteady	Airfoils	Control Surface	Wings	Wing-body	Relaxation	Time-marching	Finite element	Frequency expansion	Linear	Pressures	Forces, moments	Flutter	Wall effects
Klunker (1971)		●					●		●														
Krupp (1971)		●					●		●		●				●								
Landahl (1961)	●									●													
Magnus (1970)		●			●				●		●												
Malmuth (1976)		●					●		●		●				●								
McDevitt (1976)		●	●	●					●		●												
Murman (1972)		●					●		●		●				●								●
Murman (1973)		●					●		●		●				●								
Newman (1971)	●																						
Nieuland (1967)		●				●			●		●												
Olsen (1978)											●	●	●	●									
Shanker (1978)		●					●		●		●				●								●
Steger (1973) b		●					●		●		●												

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☆U.S.Government Printing Office: 1979 — 657-002/566